United States
Department of
Agriculture

Forest Service

Forest Health
Protection

Forest Health
Technology
Enterprise Team-
Davis
2121C Second Street
Davis, CA 95616

PARAMETERIZATION OF EVAPORATION RATES OF PESTICIDE DROPLETS

FHTET 96-40
December 1996

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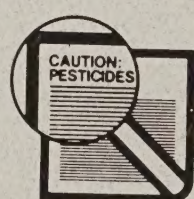
Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.



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Parameterization of Evaporation Rates of Peticide Droplets

Prepared by:

Milton E. Teske

Continuum Dynamics, Inc.
P.O. Box 3073
Princeton, NJ 08543

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Prepared for:

USDA Forest Service
Missoula Technology & Development Center
Fort Missoula, Building 1
Missoula, MT 59801

USDA Forest Service
Forest Health Technology Enterprise Team
2121C Second Street
Davis, CA 95616
(916) 757-8341

FOREWORD

Program WIND (Winds In Non-Uniform Domains) was a cooperative applied research program conducted by the USDA Forest Service (FS) and the U.S. Army, and supported by other public and private cooperators. The purpose of Program WIND was to obtain data for the evaluation of computer-based predictive mesoscale meteorological and particulate dispersion models. The program was conducted in northern California over an area approximately 80 km x 80 km bounded on the south by Sacramento, on the north by Redding, on the east by the Sierra Nevada Range foothills, and on the west by Interstate 5, and consisted of four phases - Summer Phase 1, Winter Phase II, Spring Phase III and Fall Phase IV. The field work began in the summer 1985 and ended in the fall 1987. The USDA Forest Service participated by conducting aircraft wake and dispersion studies during Phases I, III and IV. This was the first meteorlogical mesoscale study of this scale in North America in terms of the type, number, and frequency of meteorological data collection. Cooperation among the participating agencies and the advancement in meteorological instrumentation made this study possible.

The FS participated actively in Program WIND by providing a program director (Jack Barry, Washington Office, Forest Health Protection Staff), a public affairs officer (Ann Westling, Tahoe National Forest), and assistant program director (Bob Ekblad, Missoula Technology Development Center). The FS provided administrative management, coordination with the public and news media, and contracting and leasing of real estate for the numerous study and sampling sites.

The program approach was to characterize atmospheric conditions by obtaining meteorological data during each of valley wind patterns associated with the four seasons and during different times of the day. Data were used to evaluate and enhance a hierarchy of predictive meteorological models. Prior to Program WIND the models had suffered for need of a database extensive enough to characterize and quantify the physical processes at play in the atmosphere. These include models and integrated models that predict (1) wind flow over a mountain-valley complex, (2) influence of forest and crop canopies on wind flow, (3) dispersion of smoke, air pollution, dusts, seeds, pesticides and other agricultural materials and (4) effects of aircraft wake on dispersion of agricultural and forestry sprays and dry materials.

Specifically the FS interest focused on models which predict dispersion of smoke from controlled burns and movement of air pollutants, spray drift, penetration, and deposition of sprays into and on forest/range canopies. Data collected during Program WIND was also used by the FS to develop and to make FS spray dispersion models simpler and easier to use in the field.

DISCUSSION

[illegible] program conducted by the USDA Forest Service [illegible] The [illegible] of [illegible] was [illegible] for the [illegible] of [illegible]. The program was conducted in northern California [illegible] approximately [illegible] on the east by the Sierra Nevada [illegible] and the west by Interstate 5, and [illegible]. The field work began in the summer [illegible]. The USDA Forest Service [illegible] and the first meteorological [illegible] North species in terms of the [illegible] data [illegible] this study possible.

[illegible]

The purpose [illegible] data [illegible] of the day. Data were used [illegible]

[illegible]

The U.S. Army was primarily interested in a capability to predict winds as they affect obscuration from smoke and dust over an area ranging from one km to 6400 km.

While the FS reported most of its findings from Program WIND at symposia, in professional journals, and in FS reports, some data escaped reporting. This report and others being issued under the Forest Health Technology Enterprise Team (FHTET) and Missoula Technology & Development Center (MTDC) report series covers some of those unreported studies conducted by the FS in conjunction with Program WIND. By providing reports within the FHTET and the MTDC report series, the data will be more accessable to a broader audience through FS and other library searches.

<u>Key Words:</u>

forest meteorology, spray models, dispersion models, aerial application, forest canopy, spray drift, smoke behavior, forest pest management, program WIND.

John W. Barry
Director, Forest Health
Technology Enterprise Team - Davis
March 1996

Harold Thistle
Program Leader
MTDC
March 1996

Summary

Evaporation data from Colorado State University have been curve fit to generate compatible quadratic relationships for input into USDA Forest Service deposition codes. Tables of model coefficients and step-by-step instructions for extrapolating the data are included to provide easy program entry for the applicable spray solution.

Data Procedure and Results

Dennison and Wedding of Colorado State University recently conducted a wind tunnel study of evaporation rates of pesticide droplets (Ref. 1). Thirteen pesticide mixtures plus water were studied under simulated free fall conditions to extract the evaporation time history of the droplets. An extensive test matrix (composed of four droplet diameters, four air temperatures and three relative humidity levels) was invoked, with all results stored on magnetic tape. An overall error estimate of nine percent was anticipated in the test results by Dennison and Wedding due to the test procedure and facility. A portion of the data was presented in Ref. 1. A summary of the solutions tested is compiled in Table 1.

As a consequence of this work, both USDA Forest Service deposition codes, AGDISP (Ref. 2) and FSCBG (Ref. 3), have been modified to include the option of entering the effects of evaporation on droplet diameter by specifying the three model coefficients A , B and C in the equation

$$\text{Diam}(t) = A + B\,t + C\,t^2$$

where

Diam = droplet diameter (microns)
t = time (seconds).

In pursuing the original data on magnetic tape, it was discovered that the desired tapes had been overwritten. Thus, only the data plotted in Ref. 1 could be reduced to model coefficient form. The digitized data were generated by B. Thompson (private communication), and a least squares technique was programmed to determine the A , B and C coefficients for best fit of the data. A typical comparison with data is shown in Figure 1. The coefficient data are presented in Table 2.

Table 1: Description of Solutions Tested (Ref. 1)

Index	Density (gm/cm^3)	Mixture
1	0.88062	0.5 gallons of Sevin-4 oil 0.48 gallons of No. 2 Fuel oil 0.02 gallons of Automate Red B dye
2	1.03551	0.5 ounces of Polyhedra Douglas Fir Tussock Moth Nucleopolyhedrosis Virus 0.25 gallons of Molasses 0.7 gallons of water NaOH in an amount sufficient to make the pH of the mixture between 6.0 and 7.2
3	0.98770	0.8 gallons of Sevin-4 oil 0.48 gallons of No. 2 Fuel oil 0.02 gallons of Automate Red B dye
4	0.86090	0.98 gallons of No. 2 Fuel oil 0.02 gallons of Automate Red B dye
5	1.12600	0.5 gallons of Thuricide 16B 0.5 gallons of water
6	1.02004	0.5 pounds of Orthene 75S 1.0 gallons of water
7	1.04280	1.0 pounds of Orthene 75S 1.0 gallons of water
8	1.01224	2.0 quarts of Dow Esteron (2,4,5,-T) 10.0 gallons of water
9	1.00882	2.0 quarts of Dow Esteron 99 10.0 gallons of water
10	1.05404	0.5 pounds of Dipel 0.5 pounds of Shade 1.0 gallons of water 0.016692 pounds of Rhodamine B extra
11	1.03008	0.5 pounds of Dipel 1.0 gallons of water 0.016692 pounds of Rhodamine B extra
12	1.0	water
13	1.00070	5.0 ounces of Nalco-Trol 100.0 gallons of water
14	1.00140	10.0 ounces of Nalco-Trol 100.0 gallons of water

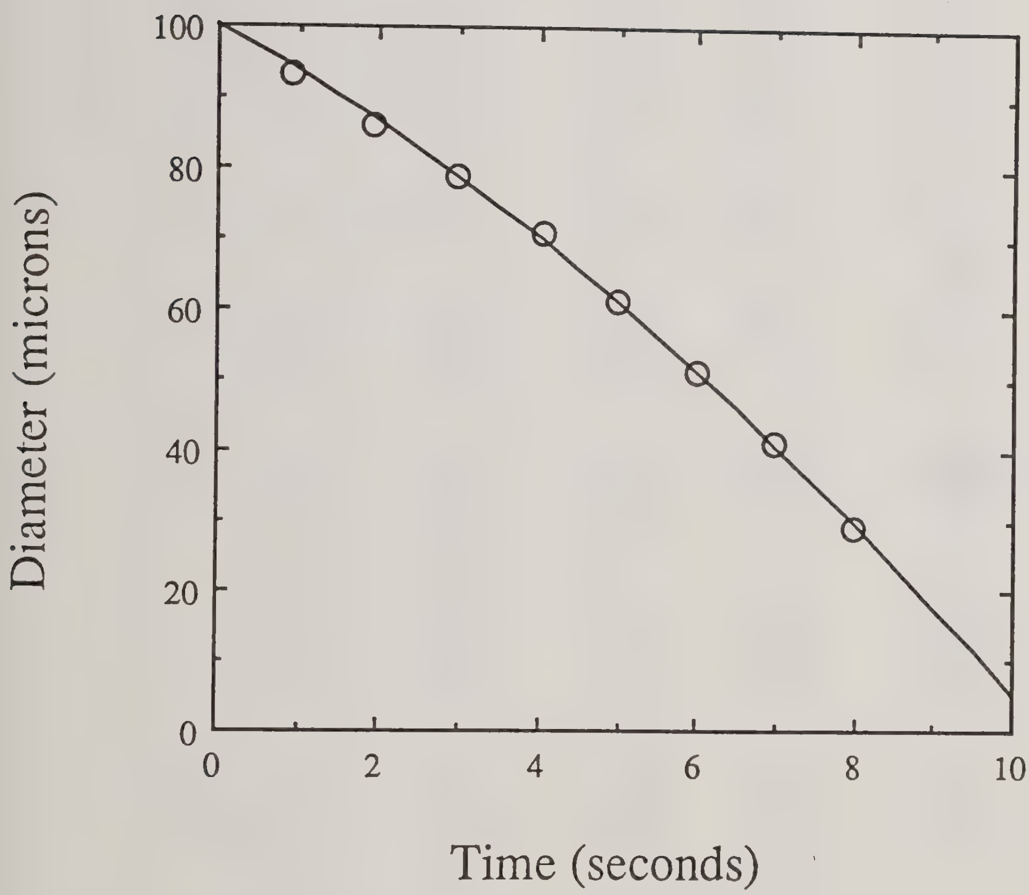

Figure 1: Comparison of tunnel evaporation data with curve fit for Solution 12; initial diameter = 100 microns, air temperature = 20 deg C, relative humidity = 20 percent. The least squares formula is

$$\text{Diam}(t) = 100.0 - 6.1375\,t - 0.3343\,t^2$$

Table 2: Model Coefficients

Figure (Ref. 1)	Solution Index	Air Temp (deg C)	Rel Hum (percent)	A (μm)	B (μm/sec)	C (μm/sec^2)
5	1	20.0	20.0	60.0	-0.1147	0.0005795
		20.0	20.0	110.0	-0.0997	0.0002564
		20.0	20.0	240.0	-0.1469	0.0005760
		20.0	20.0	410.0	-0.1131	-0.0000512
8	1	5.0	20.0	100.0	-0.0316	0.0001074
		10.0	20.0	100.0	-0.0379	0.0000668
		15.0	20.0	100.0	-0.0471	0.0000239
		20.0	20.0	110.0	-0.0931	0.0001818
11	1	20.0	20.0	110.0	-0.0999	0.0002656
		20.0	60.0	100.0	-0.0863	0.0002405
14	2	20.0	20.0	50.0	-8.7658	0.6221
		20.0	20.0	130.0	-6.2676	0.1752
		20.0	20.0	270.0	-4.8895	0.0421
		20.0	20.0	410.0	-4.0946	0.0183
25	2	5.0	20.0	110.0	-2.0800	0.0267
		10.0	20.0	120.0	-3.1428	0.0532
		15.0	20.0	120.0	-5.2166	0.1398
		20.0	20.0	130.0	-6.4201	0.1965
36	2	20.0	20.0	130.0	-6.1130	0.1696
		20.0	60.0	140.0	-3.7086	0.0364
		20.0	90.0	130.0	-2.4651	0.0317
6	3	20.0	20.0	60.0	-0.1033	0.0005071
		20.0	20.0	100.0	-0.0686	0.0001601
		20.0	20.0	240.0	-0.0646	-0.0003182
		20.0	20.0	420.0	-0.1598	-0.0002375
9	3	5.0	20.0	110.0	-0.0390	0.0000679
		10.0	20.0	100.0	-0.0383	0.0000710
		15.0	20.0	110.0	-0.0507	0.0000821
		20.0	20.0	100.0	-0.0639	0.0001005
12	3	20.0	20.0	100.0	-0.0700	0.0001761
		20.0	60.0	100.0	-0.0835	0.0001915
7	4	20.0	20.0	50.0	-0.0513	0.0000533
		20.0	20.0	110.0	-0.0666	0.0000990
		20.0	20.0	280.0	-0.1664	0.0006634
		20.0	20.0	330.0	-0.1793	0.0006621

Table 2: Model Coefficients (continued)

Figure (Ref. 1)	Solution Index	Air Temp (deg C)	Rel Hum (percent)	A (µm)	B (µm/sec)	C (µm/sec^2)
10	4	5.0	20.0	100.0	-0.0146	-0.0000345
		10.0	20.0	100.0	-0.0351	0.0000881
		15.0	20.0	90.0	-0.0388	0.0000899
		20.0	20.0	110.0	-0.0636	0.0000611
13	4	20.0	20.0	110.0	-0.0680	0.0001173
		20.0	60.0	100.0	-0.0747	0.0000936
15	5	20.0	20.0	50.0	-4.4632	0.4438
		20.0	20.0	100.0	-4.4920	0.2446
		20.0	20.0	290.0	-4.4497	0.0657
		20.0	20.0	380.0	-4.0137	0.0409
26	5	5.0	20.0	100.0	-2.6975	0.0996
		10.0	20.0	100.0	-3.6708	0.1854
		15.0	20.0	100.0	-4.4740	0.2733
		20.0	20.0	100.0	-6.2167	0.5456
37	5	20.0	20.0	100.0	-5.0247	0.3323
		20.0	60.0	100.0	-3.5133	0.1693
		20.0	90.0	100.0	-1.6839	0.0391
16	6	20.0	20.0	50.0	-10.2330	0.7280
		20.0	20.0	150.0	-7.4268	0.1278
		20.0	20.0	270.0	-4.9502	0.0185
		20.0	20.0	420.0	-3.4388	-0.0029
27	6	5.0	20.0	130.0	-1.8332	-0.01050
		10.0	20.0	140.0	-3.4821	0.00716
		15.0	20.0	140.0	-4.7848	0.03562
		20.0	20.0	150.0	-5.9955	0.03989
38	6	20.0	20.0	150.0	-6.8594	0.09904
		20.0	60.0	130.0	-4.0980	0.03587
		20.0	90.0	120.0	-1.4964	-0.00047
17	7	20.0	20.0	50.0	-8.3621	0.5884
		20.0	20.0	130.0	-6.2391	0.1330
		20.0	20.0	240.0	-3.1625	0.0100
		20.0	20.0	380.0	-4.2085	0.0244
28	7	5.0	20.0	120.0	-2.5886	0.0217
		10.0	20.0	130.0	-3.1872	0.0257
		15.0	20.0	160.0	-7.0769	0.1302
		20.0	20.0	130.0	-5.4953	0.0670

Table 2: Model Coefficients (continued)

Figure (Ref. 1)	Solution Index	Air Temp (deg C)	Rel Hum (percent)	A (µm)	B (µm/sec)	C (µm/sec^2)
39	7	20.0	20.0	130.0	-5.5853	0.0781
		20.0	60.0	140.0	-5.0716	0.0775
		20.0	90.0	110.0	-1.9063	0.0173
18	8	20.0	20.0	50.0	-10.0351	0.6889
		20.0	20.0	120.0	-6.8079	0.1340
		20.0	20.0	310.0	-5.5876	0.0139
		20.0	20.0	410.0	-4.5119	0.0012
29	8	5.0	20.0	110.0	-1.4471	-0.0341
		10.0	20.0	110.0	-3.7666	0.0088
		15.0	20.0	130.0	-4.8903	-0.0023
		20.0	20.0	120.0	-6.2940	0.0855
40	8	20.0	20.0	120.0	-4.1637	-0.0663
		20.0	60.0	140.0	-2.7895	-0.0803
		20.0	90.0	110.0	-0.5182	-0.0245
19	9	20.0	20.0	50.0	-12.5750	1.0173
		20.0	20.0	130.0	-9.4346	0.1851
		20.0	20.0	280.0	-4.4417	-0.0513
		20.0	20.0	400.0	-2.1164	-0.0326
30	9	5.0	20.0	130.0	-2.3566	-0.0502
		10.0	20.0	130.0	-2.4665	-0.0439
		15.0	20.0	130.0	-8.9751	0.1948
		20.0	20.0	130.0	-8.5600	0.1176
41	9	20.0	20.0	130.0	-7.8133	0.0647
		20.0	60.0	120.0	-2.6153	-0.0696
		20.0	90.0	130.0	-1.9572	-0.0570
20	10	20.0	20.0	50.0	-10.5260	0.9992
		20.0	20.0	130.0	-6.8225	0.2199
		20.0	20.0	290.0	-6.6731	0.0743
		20.0	20.0	420.0	-5.0956	0.0294
31	10	5.0	20.0	110.0	-2.1163	0.0162
		10.0	20.0	110.0	-4.3289	0.0921
		15.0	20.0	130.0	-5.8431	0.1302
		20.0	20.0	130.0	-6.7870	0.2116
42	10	20.0	20.0	130.0	-6.7514	0.2117
		20.0	60.0	120.0	-3.9954	0.0265
		20.0	90.0	110.0	-1.7991	-0.0070

Table 2: Model Coefficients (continued)

Figure (Ref. 1)	Solution Index	Air Temp (deg C)	Rel Hum (percent)	A (μm)	B (μm/sec)	C (μm/sec^2)
21	11	20.0	20.0	50.0	-10.8030	0.9753
		20.0	20.0	140.0	-7.4536	0.1724
		20.0	20.0	280.0	-4.3828	0.0237
		20.0	20.0	390.0	-3.2595	0.0038
32	11	5.0	20.0	120.0	-2.5664	0.0222
		10.0	20.0	130.0	-4.0313	0.0426
		15.0	20.0	130.0	-3.8285	0.0122
		20.0	20.0	140.0	-6.0584	0.0596
43	11	20.0	20.0	140.0	-6.1061	0.0675
		20.0	60.0	140.0	-4.9250	0.0436
		20.0	90.0	110.0	-2.5407	0.0275
22	12	20.0	20.0	50.0	-10.8690	-0.9249
		20.0	20.0	100.0	-6.1375	-0.3343
		20.0	20.0	240.0	-3.5386	-0.0259
		20.0	20.0	380.0	-2.5431	-0.0300
33	12	5.0	20.0	110.0	-1.6399	-0.0751
		10.0	20.0	100.0	-3.0005	-0.1750
		15.0	20.0	100.0	-3.5431	-0.2503
		20.0	20.0	100.0	-5.6546	-0.4011
44	12	20.0	20.0	100.0	-5.9072	-0.3439
		20.0	60.0	110.0	-2.3116	-0.1778
		20.0	90.0	100.0	-1.3256	-0.0180
23	13	20.0	20.0	110.0	-5.6661	-0.3342
		20.0	20.0	400.0	-2.1162	-0.0219
34	13	10.0	20.0	120.0	-0.9795	-0.4107
		20.0	20.0	120.0	-3.9073	-0.3326
45	13	20.0	20.0	120.0	-4.0762	-0.3138
		20.0	60.0	110.0	-1.1747	-0.2642
		20.0	90.0	100.0	-0.4519	-0.0593
24	14	20.0	20.0	130.0	-4.8199	-0.2681
		20.0	20.0	400.0	-3.2936	-0.0255
35	14	10.0	20.0	130.0	-1.8616	-0.3361
		20.0	20.0	130.0	-3.4725	-0.4495
46	14	20.0	20.0	130.0	-4.0621	-0.3499
		20.0	60.0	120.0	-2.3141	-0.2712
		20.0	90.0	100.0	-0.5218	-0.0525

When attempting to make use of the evaporation data included here, the following information must be determined:

STEP 1

The evaporating solution must be consistent with one of the fourteen tested solutions, or approximated by one of the fourteen solutions. If the desired solution does not fit any of the fourteen possibilities, this document cannot be used to quantify its evaporation.

STEP 2

If the initial droplet diameter, air temperature and relative humidity are within nine percent of any of the tested conditions for the desired solution, the model coefficients can be used directly as tabulated in Table 2. If not, a computation must be undertaken to determine a set of correlated model coefficients.

The original experimental data set of Dennison and Wedding contained all intersection points in the three-dimensional test matrix cube of 50, 100, 250 and 400 microns (nominal) droplet diameters; 5, 10, 15 and 20 deg C air temperature; and 20, 60 and 90 percent relative humidity, for each solution. Even with some dropout points (where data were not obtained), they accumulated 496 data runs. This data would have been sufficient to interpolate for any tested solution at any initial droplet diameter, air temperature and relative humidity.

Unfortunately, only 143 data sets remain (the data plotted in Ref. 1). These data are restricted to 20 deg C and 20 percent relative humidity for all droplet diameters; 100 microns (nominal) and 20 deg C for all percent relative humidity; and 100 microns (nominal) and 20 percent relative humidity for all air temperatures, for each solution. In statistical terms the recovered data display no interactive effects; they lie upon three intersecting edges of the test matrix cube.

To overcome this problem and populate the test matrix, approximations must be made that will generalize the B and C coefficients for any diameter, air temperature and relative humidity, for the fourteen solutions tested. The procedure is as follows.

STEP 3

The A model coefficient is the desired initial droplet diameter.

The B model coefficient is obtained by curve fitting the B coefficients determined from test data, and assuming separation of variables. Since the air temperature and relative humidity effects are known only for 100 microns (nominal), it has been assumed that their effect is similar across all droplet diameters. Thus, if a doubling of the air temperature halves the droplet diameter for 100 microns, it will do the same thing for any other initial droplet diameter. Evaporation is a complex theoretical problem even for Solution 12 (water), and is more so with additives. Since evaporation reduces as the air temperature goes to zero and the relative humidity approaches 100 percent, a separation of variables effect seems the easiest (and most obvious) to impose on the data. Thus the B correlated model coefficient is approximated by the expression

$$B = a D^{b} T^{c} H^{d}$$

where

D = initial droplet diameter (microns)
T = air temperature (deg C)
H = relative humidity (0 - 100).

The B model coefficients in Table 2 are plotted logarithmically to recover the least squares power law for each variation. Typical correlation plots are shown in Figure 2. Consistent tabulated results are given in Table 3.

The C model coefficient is more difficult to quantify because it is more difficult to extract accurately from the data. Separation of variables will again be assumed. In this case the air temperature and relative humidity effects will be taken as linear

$$C = e D^{f} \left(\frac{T}{20} \right) \left(\frac{100 - H}{80} \right)$$

The C model coefficients in Table 2 are then plotted logarithmically to recover the least squares power law for initial droplet diameter. A typical correlation plot is shown in Figure 3. Consistent tabulated results are also given in Table 3.

EXAMPLE

For Solution 12 (water) with an initial droplet diameter of 200 microns, air temperature of 12 deg C and relative humidity of 50 percent, substitution of the appropriate correlation model coefficients from Table 3 gives

$$\text{Diam}(t) = 200.0 - 1.052\, t - 0.028\, t^{2}$$

as the equation to represent evaporation effects for these specified conditions.

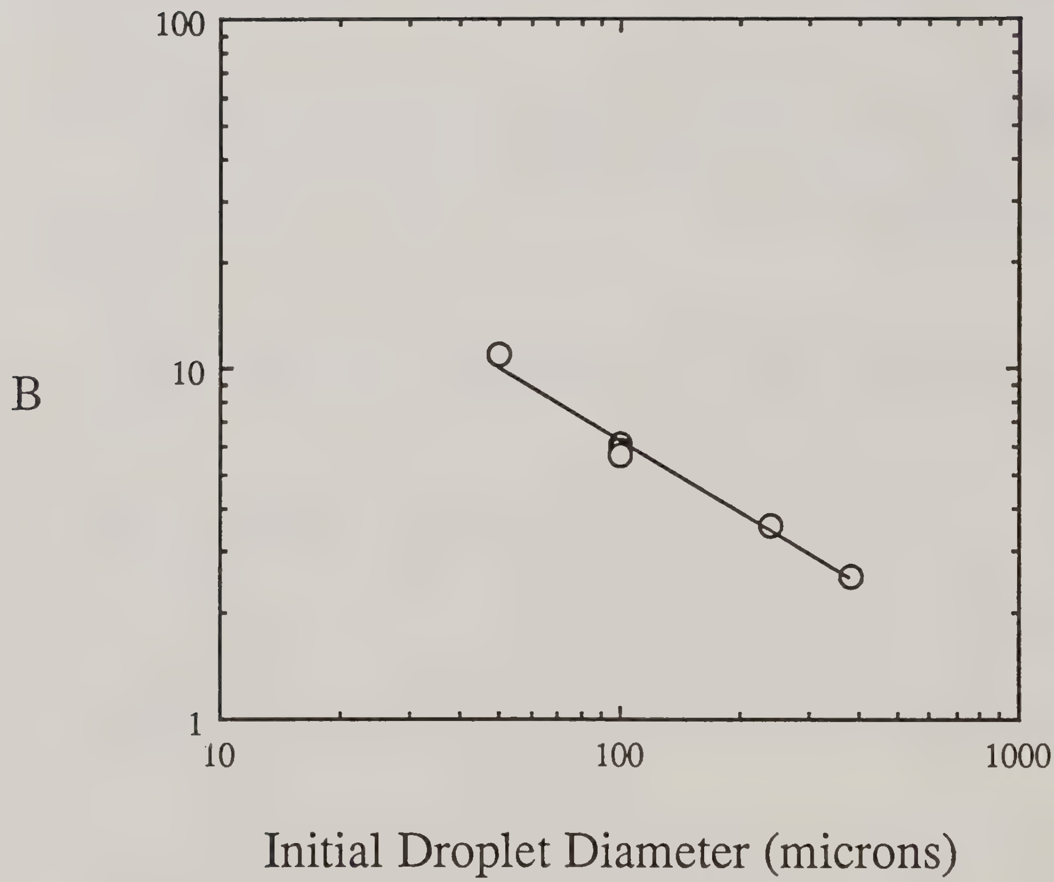

Figure 2a: Correlation of B model coefficients for Solution 12 for initial droplet diameter.

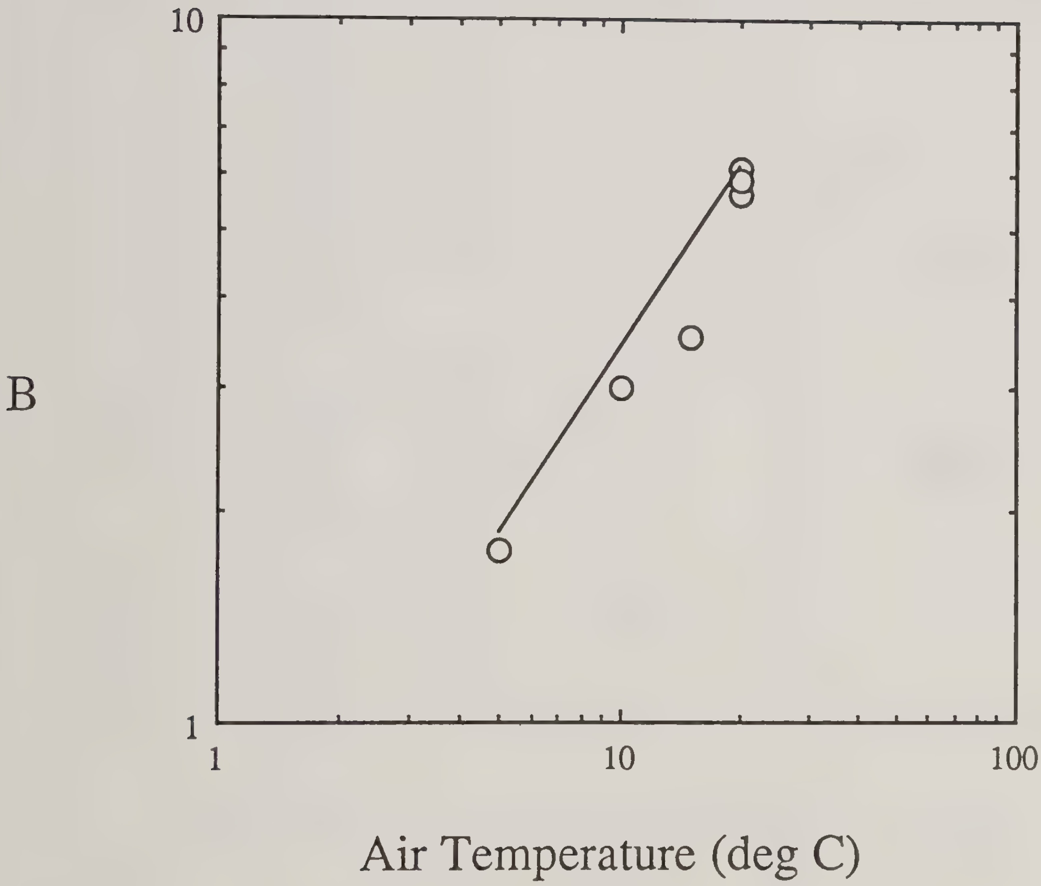

Figure 2b: Correlation of B model coefficients for Solution 12 for air temperature.

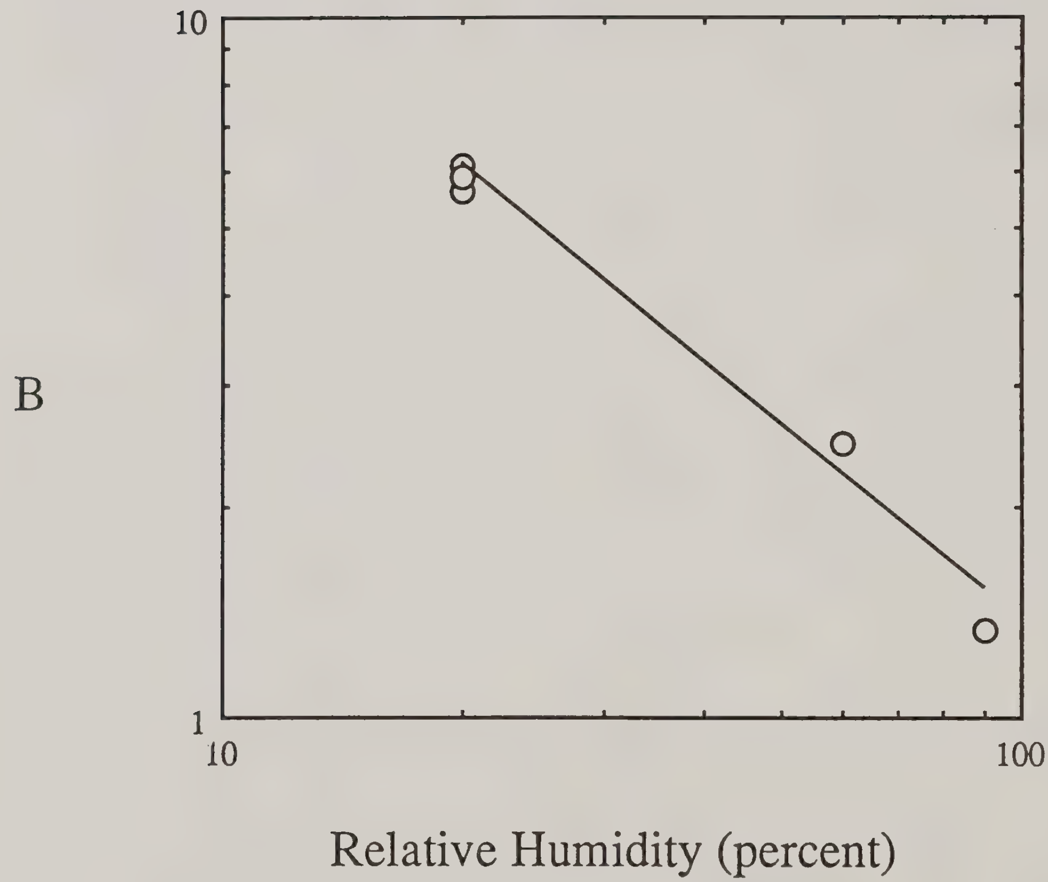

Figure 2c: Correlation of B model coefficients for Solution 12 for relative humidity.

Table 3: Correlated Model Coefficients

Solution Index	a	b	c	d	e	f
1	-0.00719	0.1015	0.8458	-0.1031	0.0139	-0.8166
2	-14.666	-0.3577	0.8670	-0.5701	637.54	-1.7104
3	-0.00370	0.2390	0.4525	0.1941	0.0002	0.0076
4	-0.00006	0.7506	0.9991	0.1777	0.0	1.5380
5	-11.342	-0.0837	0.4758	-0.6312	115.17	-1.3064
6	-62.021	-0.5001	0.9854	-0.9070	20530.0	-2.5287
7	-32.849	-0.4233	0.6678	-0.5740	678.54	-1.8452
8	-78.219	-0.3092	0.9603	-1.3011	45644.0	-2.7627
9	-379.67	-0.8332	1.0691	-1.0303	314.7	-1.5743
10	-23.888	-0.2871	0.8613	-0.7910	508.98	-1.5928
11	-71.441	-0.5725	0.7124	-0.5780	23465.0	-2.5379
12	-172.58	-0.6829	0.8716	-0.9325	-2604.2	-1.9729
13	-11.443	-0.6243	2.1690	-1.4883	-10550.0	-2.1824
14	-10.547	-0.1908	1.1325	-1.1394	-28629.0	-2.3251

$$\mathrm{Diam}\,(t) = D + a\,D^{b}T^{c}H^{d}\,t + \frac{e\,D^{f}\,T\,(100 - H)}{1600}\,t^{2}$$

where

Diam = droplet diameter (microns) time history variation
D = initial droplet diameter (microns)
T = air temperature (deg C)
H = relative humidity (0 - 100)
t = time (seconds)

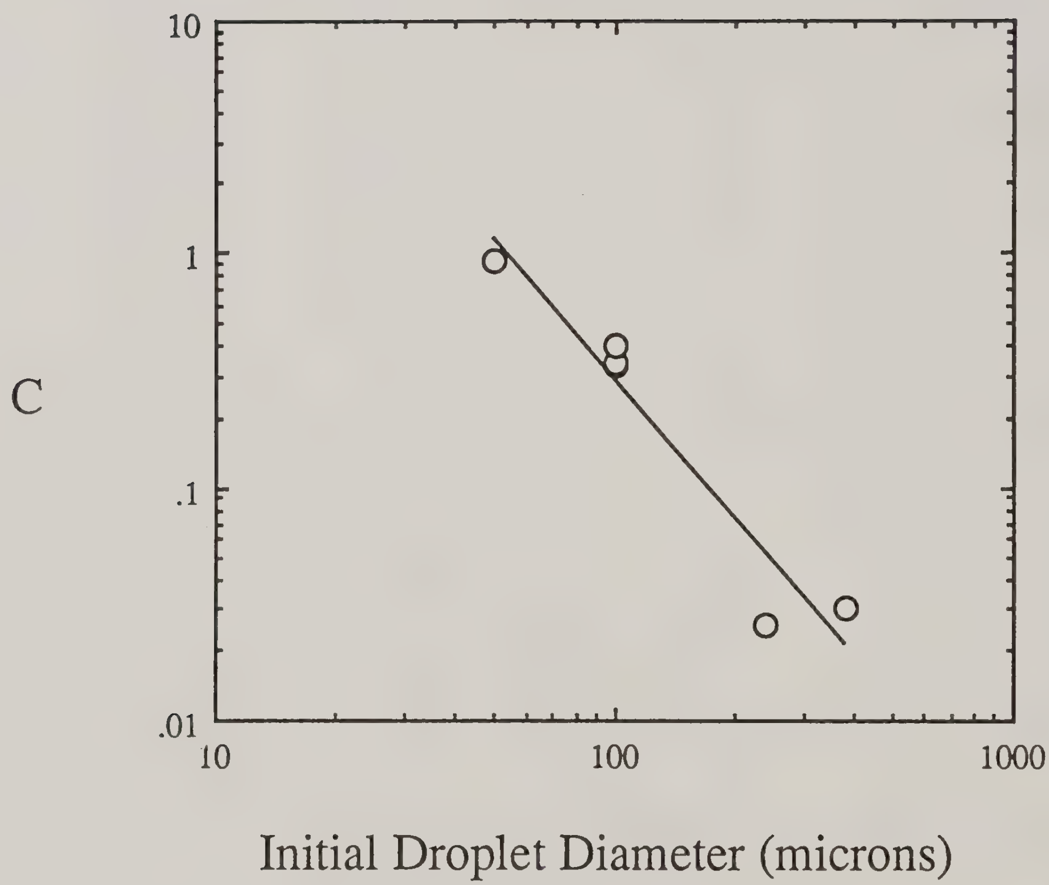

Figure 3: Correlation of C model coefficients for Solution 12 for initial droplet diameter.

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